

Eulerian And Lagrangian Predictability Of Oceanic Flows

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LONG-TERM GOALS

Our long-term goals are to obtain a better understanding of the processes controlling the predictability of coastal and open-ocean flows and to develop tools that can more efficiently predict such flows.

OBJECTIVES

Our work has a number of objectives:

- To determine the predictability time scales of the meandering of oceanic fronts
- To determine the ways in which predictability in such a flow is lost, the physical processes responsible, and the sites of most rapid error growth
- To develop simple, efficient data assimilation schemes that can be used to forecast the behavior of such fronts
- To develop a method of determining the degree of optimality of a “new” observation with regards to improving a forecast, and the nature of the improvements that are possible
- To design and test adaptive sampling strategies to guide efficient data sampling for improved forecasting

APPROACH

To meet our objectives we have adopted a two-stage approach. We are first developing measures of predictability, assimilation schemes and adaptive sampling techniques in the relatively simple context of a two-layer, quasigeostrophic model of a double-gyre, wind-driven circulation. We will then extend these to the more complex problem of a shelf-break front using a non-hydrostatic code. Steve Meacham developed the two-layer double-gyre model, together with its associated tangent linear and adjoint codes. Using these, he developed a scheme for determining the singular vectors of the time-dependent, nonlinear double-gyre flow. Amala Mahadevan analyzed the singular vectors obtained with this code, diagnosing their exchange of energy with the time-dependent fiducial flow and classifying them. She also examined a flow that exhibited strong decadal variability and determined how the structure of the singular vectors and the values of the associated singular values varied with time and with the structure of the nonlinear flow.

Dr. Mahadevan assisted Dr. Jim Lu of MIT in developing a reduced gravity version of this set of codes, for use in another project in the predictability DRI, that directed by Dr. Paola Rizzoli. We have compared the structure of the singular vectors and values and the time-dependent changes in predictability observed with our baroclinic model with those observed by the MIT group in their reduced gravity model. Dr. Meacham has developed a reduced Kalman filtering assimilation scheme

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for the baroclinic, quasigeostrophic model that uses singular vectors as the basis functions for the reduced space in which the Kalman filter is implemented. This has been tested to establish that it can reduce forecast error and is being compared with other approaches to assimilation. Dr. Meacham has also tested the effectiveness of using the extrema of the leading singular vectors to determine the sites at which observations should be made. The improvement in forecast error has been compared with that obtained using observations taken at random and gridded sites in the most energetic part of the flow. We have developed a simple theoretical demonstration which shows that targeting observations at the extrema of the leading singular vectors, while useful, is not, in general, optimal and we are exploring ways of developing targeting schemes that are more nearly optimal.

WORK COMPLETED

- Tangent linear and adjoint counterparts of a non-linear, two layer, quasigeostrophic, double-gyre model have been developed
- The numerical code to calculate singular vectors of the double-gyre model has been developed and tested
- The leading singular vectors of the double-gyre model have been calculated for a variety of flows of increasing complexity (stationary, periodic and chaotic). Their structure and time dependence has been diagnosed and used to demonstrate temporal variations in predictability.
- A new data assimilation scheme has been developed that implements a reduced Kalman filter using singular vectors as basis functions for the representation of error covariance matrices
- The use of targeted observations based on the structure of singular vectors has been tested.

RESULTS

- The leading singular vectors of the time-dependent, double-gyre circulation fall into two classes. One consists of structures that are roughly symmetric about the axis of the jet that forms the main inter-gyre front, are intensified near the western boundary, and represent meridional fluctuations in the separation point of the jet. The second class consists of singular vectors that are associated with meandering disturbances to the inter-gyre front.
- The dominant instabilities driving singular vector growth are mixed instabilities (mixed barotropic and baroclinic)
- The predictability time scales indicated by the size of the leading singular values are, unsurprisingly, of the order of the synoptic time scale
- The magnitudes of the leading singular values, smoothed over the synoptic time scale, and hence the predictability time scale, vary significantly (20 – 50%), but not by order of magnitude, during the low frequency vacillations of the structure of the flow that are part of the evolution of the double gyre circulation at moderate Reynolds numbers. During the phase of this vacillation that corresponds to a rapid reorganization of the flow with enhanced mesoscale variability, the dominant singular values oscillate rapidly: the presence of strong mesoscale features makes the flow less predictable in the enstrophy norm
- From a theoretical point of view, we have shown that singular vectors form a natural basis (in the mathematical sense of natural) for describing the evolution of the error covariance matrix in a Kalman filter assimilation scheme.
- From a practical point of view, a reduced Kalman filter constructed using a basis of 12 singular vectors demonstrated skill in enabling a perturbed twin assimilation/forecast experiment to converge towards a control run. In its present form, this assimilation scheme is considerably

less efficient than a scheme using simple direct insertion of data and smoothing. We are exploring ways of improving the efficiency of the scheme by taking advantage of some persistence in the structure of the singular vectors.

- Restricting observations to a rectangular sub-domain that contains the most energetic features of the flow and using an assimilation scheme based on direct insertion and smoothing, we have demonstrated that targeted observations taken from the parts of the sub-domain where the magnitude of one of the leading four singular vectors is greater than a threshold value are considerably more effective at reducing the error in perturbed twin experiments than a larger number of observations taken at random in the energetic sub-domain
- We have constructed a simple theoretical demonstration which shows that using the extrema of the singular vectors to determine the optimum location for targeted observations is not optimal. This argument also shows that an optimal approach to targeted observations must take into account both dynamical information, as embodied in the singular vectors, and information about the error covariance fields.

IMPACT/APPLICATIONS

We anticipate that these idealized experiments will, in particular, provide guidance in how to approach the problem of the predictability of the shelfbreak front, which is the second phase of this project. We also anticipate the more general outcome, that this work and its ongoing extensions will help develop a conceptual and quantitative framework for the problem of using targeted observations to improve flow forecasts.

TRANSITIONS

Some of our modeling and singular vector computation software have been used by Prof. Rizzoli's group.

RELATED PROJECTS

Drs. Rizzoli and Lu at MIT have embarked on a study of the predictability of a reduced gravity model of the double-gyre circulation. We have had a fruitful interaction with Drs. Rizzoli and Lu in which we have compared the characteristics of the singular vectors of baroclinic and reduced gravity flows.